Chapter 108: Management of the Impaired Airway in Adults

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The management of laryngeal and upper tracheal stenosis continues to be a formidable challenge to the otolaryngologist-head and neck surgeon (OHNS). Successful repair requires establishing an adequate airway while preserving phonation during wound healing of a semirigid tubular structure. Concentric scar contraction is a normal part of this process, which tends to narrow the lumen progressively and undermine the best surgical efforts. In addition, laryngotracheal injuries are rarely identical among patients. The injury may vary in its location, severity, duration, cause, and degree of functional impairment. Selection of the appropriate specific surgical repair requires consideration of these factors in concert with the patient's associated injuries, medical problems, and psychosocial milieu. The variety of different techniques described for a specific problem attests to the difficulty of obtaining consistent long-term results with any one specific repair and to the complexity of laryngotracheal stenosis.

The purpose of this chapter is to discuss the surgical management of adult laryngeal and upper tracheal stenosis. The cause and pathophysiology of laryngotracheal stenosis will be discussed as they relate to surgical principles; the main causes are outlined in the box. Surgical options and controversies will then be evaluated in the context of selecting the appropriate technique, and the more common procedures for specific problems will be addressed.

Box: **Causes of adult laryngeal and upper tracheal stenosis**

- Trauma
  - External laryngotracheal injury
    - Blunt neck trauma
    - Penetrating wound of the larynx
  - Internal laryngotracheal injury
    - Prolonged endotracheal intubation
    - Posttracheotomy
    - Postsurgical procedure
    - Postirradiation therapy
    - Endotracheal burn
      - Thermal
      - Chemical
- Chronic inflammatory disease
  - Bacterial: diphtheria
  - Syphilitic
  - Fungal: histoplasmosis
    - Tuberculosis
    - Leprosy
    - Sarcoidosis
    - Scleroma
- Benign neoplasms
  - Intrinsic

- Papillomas
      - Chondromas
      - Minor salivary gland
      - Neural
    - Extrinsic
      - Thyroid
      - Thymus
- Malignant neoplasms
  - Intrinsic
    - Squamous cell carcinoma
    - Minor salivary gland
    - Sarcomas
    - Lymphoma
  - Extrinsic
    - Thyroid
- Collagen vascular disease
  - Wegener's granulomatosis
  - Relapsing polychondritis
  - Other.&

Classification of Stenosis

A general classification of adult laryngotracheal stenosis is outlined in the box. The purpose of this classification is to define and discuss the more specific problems for which several surgical approaches have been proposed. These injuries frequently occur in combination; therefore, accurate identification of the specific and most debilitating prolem(s) is essential.

Box: **Classification of stenosis**

- Acute stenosis
  - Postintubation
    - Mucosal ulceration
    - Granulation tissue
    - Vocal cord paralysis
    - Arytenoid dislocation
  - Posttrauma
    - Soft-tissue injuries
      - Hematoma
      - Laceration
    - Cartilaginous fractures
      - Hyoid
      - Thyroid
      - Cricoid
    - Neurogenic
    - Ligamentous
      - Cricoarytenoid dislocation
      - Laryngotracheal separation

- Chronic stenosis
  - Supraglottic stenosis
  - Glottic stenosis
    - Anterior
    - Posterior
    - Complete
    - Anterior, posterior, and complete with vocal cord immobility
  - Subglottic stenosis
  - Cervical tracheal stenosis
    - Cicatricial membranous
    - Anterior wall collapse
    - Complete stenosis.&

The most common causes of laryngotracheal stenosis continue to be external trauma to the neck and prolonged endotracheal intubation. Both can result in acute and chronic stenosis; however, the pathophysiologic processes that lead to chronic stenosis differ. When the laryngotracheal complex is injured by external trauma, disruption of the cartilaginous framework, hematoma in the laryngeal spaces, and mucosal disruption usually result. Resorption of the hematoma can cause cartilage loss and extensive deposition of collagen. Subsequent scar contracture will result in stenosis and loss of motility. The location and severity of the injury are variable and depend on the trauma sustained (Stell et al, 1985). In contrast, the injury from endotracheal intubation is usually initiated by ischemic necrosis of mucosa by the endotracheal tube (Burns et al, 1979; Weymuller, 1988; Whited, 1984). The mucosal ulceration in the presence of bacterial infection can lead to perichondritis and chondritis with cartilage resorption. Healing occurs by secondary intention with subsequent submucosal fibrosis and scar contraction. Injuries from endotracheal intubation occur primarily in the posterior glottis as a result of pressure exerted by the wall of the tube and tracheal injury from pressure of the cuff on tube tip. The latter injury has been reduced significantly with the advent of low-pressure, high-volume cuffs. Other factors, including tube size, tube composition, duration of intubation, laryngeal movement, and host systemic characteristics, also contribute to the development of laryngotracheal stenosis. However, with the widespread acceptance and use of endotracheal intubation to provide ventilatory and airway support, preventive efforts have been directed toward modifying endotracheal tube design (Santos et al, 1989; Weymuller, 1988).

Surgical Principles

Goals

The ultimate goal of any surgical procedure designed to correct laryngotracheal stenosis is to establish a satisfactory airway, which implies decannulation. While attempting to accomplish this goal for a patient, the OHNS must make every effort to preserve the other important laryngeal functions of phonation and airway protection.

In view of the previous discussion regarding the pathogenesis of laryngotracheal stenosis, several guidelines should be considered in determining appropriate management. Accurate assessment of the stenosis in terms of location, dimensions, quality (soft vs. fibrous), associated vocal cord paralysis, and degree of functional impairment is essential. Initial evaluation should therefore include a history detailing the subjective degree of impairment perceived by the patient together with objective measures (Davidson et al, 1987). Indirect laryngeal examination followed by direct laryngoscopy and bronchoscopy is essential. High-resolution computed tomography (CT) scan of the larynx and trachea may be useful, particularly in cases in which prior repairs have been unsuccessful, the extent of cartilage loss is uncertain, or the extent or severity of the stenosis cannot be adequately determined from indirect laryngoscopy or endoscopy.

The second consideration is to reestablish structural support. This is usually accomplished by repositioning of existing cartilage or more commonly through the use of cartilage or bone grafts. Although this tenet has recently been challenged (Eliachar et al, 1989), structural support is important because of Bernoulli's principle, which states that as airflow increases within a tube, the pressure exerted on the walls of the tube decreases, predisposing to collapse of a flaccid tube. This is particularly applicable in an area of stenosis, since airflow through the stenosis is much more rapid than that immediately above and below the stenosis.

Enhanced remucosalization and minimizing formation of scar tissue are vital for successful repair. These can be accomplished through preservation of existing mucosa and judicious use of antibiotics, stents, and skin or mucosal grafts to minimize infection, granulation tissue formation, and subsequent collagen deposition. The considerable controversy in this area has produced a variety of biases when examining any specific repair.

Timing of repair

The importance of early diagnosis and management of acute laryngotracheal stenosis has long been recognized. This injury is often sustained by blunt or penetrating trauma to the neck and can be associated with a multitude of other organ system injuries, particularly if the injuries are the result of a motor vehicle accident. The diagnosis of laryngeal injury is not difficult unless the patient is unconscious or the severity of other injuries overshadows the laryngeal injury. The classic symptoms and signs are odynophagia, hemoptysis, hoarseness of aphonia, loss of normal laryngotracheal landmarks, and subcutaneous emphysema. The status of the airway determines the initial treatment. If the airway is significantly compromised, a formal trachetomy should be performed if time permits, otherwise cricothyroidotomy is indicated. If the airway is marginal but adequate, the time elapsed since the initial injury is important since most laryngeal edema and hematoma develop within the first 6 hours (Miles et al, 1971; Montgomery, 1989). Once the airway is satisfactorily secured, cervical spine injury must be evaluated, associated shock managed, and therapy of other injuries prioritized and addressed.

Proper evaluation of the degree of laryngeal injury includes indirect or fiberoptic examination of the larynx, followed by high-resolution CT scan of the laryngotrachea if distortion of the normal endolaryngeal anatomy or function is seen (Schaefer and Brown, 1983). Direct laryngoscopy, with or without bronchoscopy and esophagoscopy, is performed in all cases in which significant injury is suspected when indications for exploration and repair are met (see the next section). Several authors have reported good results with open repair of acute stenosis performed within the first 2 weeks after injury (Olson and Miles, 1971; Schaefer, 1982; Whited, 1978). Most advocate early exploration as soon as the patient's condition permits, preferably within the first 7 to 8 days. Montgomery (1989) emphasizes the importance of undertaking repair 3 to 10 days after the initial injury. During this period, the acute reaction of edema and ecchymosis has subsided, facilitating accurate cartilaginous and mucosal repair.

The timing of repair of a chronic laryngotracheal stenosis is generally more elective. The development of stenosis requires scar contracture; therefore, the onset of symptoms is more insidious. Urgent tracheotomy is rarely required but may be necessary during the course of evaluation or treatment if the stenosis is severe. The second situation arises in chronic laryngotracheal stenosis secondary to intubation. Several attempts at extubation usually fail and require tracheotomy. The diagnosis of irreversible stenosis is usually established at this time, and repair can be performed electively after a thorough evaluation.

Endoscopic versus open repair

An endoscopic approach is applicable when acute stenosis develops secondary to granulation tissue subsequent to extubation. The reported incidence ranges from 2% to 33% (Santos et al, 1989; Whited, 1984). Development of a true vocal cord granuloma can occur up to 8 weeks after extubation. Early removal of these granulomas may be beneficial since only 50% resolve spontaneously (Santos et al, 1989). The more common cause of postextubation acute stenosis was vocal cord paralysis, which is not usually managed endoscopically.

Endoscopic repair of acute laryngotracheal stenosis after blunt or penetrating neck trauma is not indicated. Successful management requires recognition of severe injuries, followed by direct visualization and repair, usually via a laryngofissure approach.

Indicators of severe laryngotracheal injury that would warrant open repair after blunt injury to the neck are (1) increacing airway obstruction requiring tracheotomy, (2) cervical emphysema, (3) clinical or radiographic evidence of fracture dislocation, (4) extensive mucosal lacerations, or (5) exposed cartilage. Recognition of the nonsurgical nature of laryngeal injuries is made evident by minimal or no airway compromise, mobile vocal cords, and absence of hemoptysis and cervical emphysema. These injuries usually involve soft-tissue contusion or hematoma of the aryepiglottic folds and false or true vocal cords and are satisfactorily managed with voice rest, humidification, and administration of antibiotics and short-term steroids (Cummings et al, 1984; Montgomery, 1989; Ogura and Biller, 1971; Olson and Miles, 1971).

The indications for endoscopic versus open repair of chronic laryngotracheal stenosis are less well defined. The development and widespread use of the CO_2 laser have resulted in a variety of endoscopic procedures to manage glottic and subglottic stenoses that traditionally have been managed by open repair. The theoretic advantage of the CO_2 laser are (1) delay in the formation and maturation of collagen in laser wounds, thereby allowing reepithelialization before scar formation; (2) minimal deep-tissue injury; and (3) more precise control and hemostasis, facilitating preservation and use of existing mucosa in the repair (Friedman et al, 1983; Hall, 1971). Because of these advantages, some authors have advocated initial endoscopic management of chronic laryngotracheal stenosis, reserving open repair for those cases which fail to resolve with endoscopic management (Dedo and Sooy, 1984;

Friedman et al, 1983). The advantage of this approach is that an open surgical repair may be avoided in some instances; however, several endoscopic procedures are usually required for a successful result.

In a frequently cited study (Simpson et al, 1982) the factors associated with a poor result or failure of endoscopic management included circumferential scarring with cicatricial contracture, a scar greater than 1.0 cm in vertical height, tracheomalacia or loss of cartilage, previous history of severe bacterial infection associated with tracheostomy, and posterior glottic stenosis with arytenoid fixation.

Repair requirements

Use of cartilage and bone grafts

The first requirement for successful repair of acute or chronic laryngotracheal stenosis is establishment of an intact, reasonably shaped skeletal framework to provide a scaffold for the airway. It is generally agreed that acute, blunt injuries to the larynx, in which cartilage is fractured and displaced, are best managed with open reduction and stabilization of the fragments. In chronic injuries, the cartilage is often absent as a result of resorption of devitalized segments or of chondritis and subsequent chondromalacia or necrosis. In either event, the absent cartilage is replaced by scar. Because airflow in a tube is proportional to the fourth power of the diameter (Poiseuille's law), subsequent airway collapse and scar contraction produce significant stenosis. Therefore the indications for cartilage or bone grafts are to reestablish airway support and to provide luminal augmentation.

An ideal cartilage or bone graft does not exist. This is evidenced by the variety of grafts described, including rib, iliac crest, hyoid bone, epiglottis, thyroid cartilage, composite auricular cartilage, and nasal septal cartilage grafts (Burstein et al, 1986; Duncavage et al, 1989; Fry et al, 1985; McComb, 1967; Morganstein, 1972; Olson and Sullivan, 1985). Free perichondrial grafts and vascularized periosteal grafts have been evaluated for their chondrogenic or osteogenic capabilities (Friedman et al, 1986; Kon and Vandenhooff, 1983). The characteristics of an ideam mesodermal graft include (1) rapid healing with minimal long-term graft resorption (which is best seen in vascularized grafts), (2) adequate strength and size of graft, (3) minimal donor site morbidity, (4) presence of an accompanying epithelial lining, (5) single-stage reconstruction, and (6) donor site within the same operative field.

The rib/costal cartilage graft is most commonly employed because of its size, strength, and relative ease of harvesting. Vascularized hyoid and thyroid cartilage grafts have enjoyed considerable success (Burstein et al, 1986; Fry et al, 1985; Wong et al, 1978) but are limited by the amount of cartilage available. Composite auricular and nasal septal cartilage has the advantage of providing simultaneous epithelial repair but generally lacks adequate size and rigidity when large grafts are required. Perichondrial and periosteal grafts have not gained widespread acceptance because of the lack of adequate strength and the need for prolonged stenting.

Use of skin and mucosal grafts

The second requirement of successful repair of acute and chronic laryngotracheal stenosis is the establishment of a completely epithelialized lumen of reasonably normal size and shape. In acute injuries the ideal method is primary closure of mucosal lacerations after minimal debridement of nonviable tissue. In chronic stenosis, excision of scar should be accomplished with preservation of as much overlying mucosa as possible. Small mucosal defects can be left to remucosalize with minimal detrimental effects (Montgomery, 1989). The area of controversy lies in the use of epithelial grafts to resurface large defects in acute and chronic stenosis. In both cases the same principles of wound healing apply to the traumatic wound or the newly created surgical wound. Wounds that heal by secondary intention form granulation tissue and deposit collagen, which must later contract until covered by epithelium (Olson, 1979). When the denuded area is secondarily infected, particularly after tracheotomy, epithelialization can be prolonged, and excessive granulation tissue and scar formation result (Sasaki et al, 1979). Epidermal grafts have been advocated to interrupt this process and result in healing similar to that of primary intention with minimal collagen deposition. When a stable cartilaginous framework is present, the tendency for the epidermal graft to contract is less because the laryngeal skeleton acts as an external splint (Thomas and Stevens, 1975). The disadvantage of epidermal grafts in laryngotracheal reconstruction is that the larynx is not an ideal site to accept grafts. The recipient bed is often not well vascularized, the larynx is in constant motion with swallowing and neck movements, and the bed is potentially contaminated when a tracheotomy is present. A nonviable epidermal graft in the airway can become infected, exacerbating the process of healing by secondary intention. An epidermal graft is useful when a large mucosal defect is present with adequate cartilaginous support. When cartilage or bone grafts that would require prolonged rigid internal stenting (see the next section) are used, epidermal grafts may be detrimental. In this instance, satisfactory results can be obtained by allowing healing and mucosalization to occur around the stent and by not introducing a graft that, if infected, could jeopardize the skeletal reconstruction.

Use of stents

Internal laryngeal and subglottic stenting is widely employed with acceptable results; however, questions about the indications for stenting, optimal type of stent, and duration of stenting remain largely unresolved. Internal stenting with soft or firm materials has been shown to increase local infection, mucosal ulceration, and granulation tissue and is directly related to the duration of stenting (Thomas and Stevens, 1975). Capillary blood flow ceases with pressure of 20 to 40 mm Hg in mucosa closely adherent to cartilage, which can initiate ischemic mucosal injury (Nordin et al, 1977). Therefore, several authors advocate avoiding internal stenting unless absolutely necessary and minimizing duration of stenting. However, internal stenting is commonly used for certain specific indications: (1) to provide support for cartilage and bone grafts or to splint displaced cartilage fragments in the desired position, (2) to allow approximation and immobilization of epidermal grafts to a recipient site, (3) to separate opposing raw surfaces during healing, and (4) to maintain a lumen in a reconstructed area that lacks adequate cartilaginous support and requires scar formation.

The optimal type of stent has not been determined, as evidenced by the variety of stents available. A tantalum (McNaught, 1950) or umbrella silicone keel (Montgomery and Gamble, 1970) is very useful for anterior glottic webs, but for more severe laryngotracheal stenosis a variety of stents are commonly used. These include the Montgomery laryngeal stent, the Aboulker stent, the "swiss roll" siliconized rubber (Silastic) stent, and the "finger cot" stent. Each has proponents who describe good results (Evans, 1977; Harris and Tobin, 1970; Montgomery, 1989; Zalzal, 1988). In general, a soft stent should be used to minimize pressure on mucosal surfaces when cartilaginous support is satisfactory and the indication for stenting is to splint an epidermal graft or to separate opposing raw mucosal surfaces. A finger cot with a povidone-iodine- (betadine-) soaked sponge is an excellent soft stent; an alternative is a Montgomery laryngeal stent that is firm but conforms to the normal endolaryngeal contours. A firm stent is required when the cartilagineous framework or graft requires splinting or when inadequate cartilage is present, requiring that luminal support be achieved through collagen deposition and scar contraction. A solid stent is preferable to a hollow stent for minimizing aspiration. A soft, siliconized rubber (Silastic) Montgomery T-tube is commonly used for subglottic and upper tracheal stenosis; appropriate patient selection and education are essential because this is a single-lumen tube with greater risk of airway obstruction (Cummings, 1984b; Montgomery, 1989). An Aboulker stent can be used for subglottic or combined subglottic and laryngeal stenosis. The advantage of this stent is that it is used with a double-cannula metal tracheostomy tube but is secured to it, preventing removal of the tracheostomy tube (Zalzal, 1988).

There is no uniformly accepted optimal duration of stent placement. Most authors recommend a 6- to 8-week period, but the duration varies from 2 weeks to several months (Harris and Tobin, 1970; Manas, 1975; Schuller, 1980). A 2- to 3-week duration is usually sufficient if only mucosal healing or epidermal graft take is required. If the laryngeal skeleton is adequate but requires splinting to maintain the appropriate position, a 6- to 8-week period is generally accepted. However, if the cartilaginous framework is deficient and mature scar is important in providing structural strength, prolonged stenting is indicated to allow scar contraction around an inert, firm object. Successful prolonged stenting has been reported for intervals up to 14 months. In this situation, the problem arises in premature stent removal, usually before sufficient scar contraction has occurred (Schuller, 1980).

Surgical Management of Acute Stenosis

Postintubation stenosis

Acute laryngeal injury from endotracheal intubation manifests as hoarseness with varying degrees of upper airway obstruction within 24 hours of extubation. The site of injury is classically over the posterior glottis and posterolateral cricoid arch. In mild cases, the injury is limited to mucosal erythema and ulceration, which usually resolve within 4 weeks (Santos et al, 1989). In more severe cases, progressive upper airway obstruction necessitates tracheotomy, usually after several attempts at extubation are unsuccessful. The differential diagnosis in this situation includes vocal cord paralysis, granuloma, arytenoid dislocation, and severe mucosal ulceration with laryngeal edema. Conversely, patients who are chronically intubated may undergo tracheotomy for prolonged ventilatory support or pulmonary toilet. Acute laryngeal injury may be unrecognized until attempts at decannulation are unsuccessful as a result of undetected development of chronic stenosis. Early recognition by indirect or fiberoptic laryngeal exam is important in either instance so that acute injuries can be addressed in a timely manner, which is often at the time of tracheotomy.

Posterior glottic mucosal erythema and ulceration occurs in > 90% of patients intubated for > 72 hours and spontaneously resolves in 70% of patients. Delayed development of granuloma may occur in 27% (Santos et al, 1989). The implication of this finding is twofold: antibiotics should be considered in patients extubated after 72 hours of intubation in an attempt to prevent ascending bacterial infection and formation of granulation tissue. Second, patients who require tracheotomy after prolonged endotracheal intubation who have extensive posterior glottic ulceration are at risk of developing chronic posterior glottic stenosis. This is the result of the effect of the tracheotomy in reducing the activity of the posterior cricoarytenoid muscle, which results in prolonged contact of the raw edges of the posterior glottis. Posterior glottic stenosis can be prevented in this instance by endoscopic placement of a synthetic implantation fabric (Teflon) keel (Langman et al, 1989) or a soft finger cot stent at the time of tracheotomy for 2 to 3 weeks to allow remucosalization without development of posterior glottic web.

Granular stenosis resolves spontaneously after removal of the endotracheal tube and nasogastric tube in most cases (Santos et al, 1989). Surgical management by suspension microlaryngoscopy and CO_2 laser exision is indicated when the granuloma causes upper airway obstruction or when it does not spontaneously resolve and hoarseness persists. These are often bilateral and care should be taken to prevent opposing of raw mucosal surfaces when a tracheotomy is present.

Vocal cord paralysis may be acute or may be delayed in onset. It is usually unilateral. Intubation with a large endotracheal tube in conjunction with a nasogastric tube is thought to contribute to the pathophysiologic mechanism. Inflammation of the cricoarytenoid joint has been demonstrated in animal models (Weymuller, 1988), and most cases resolve spontaneously. The efficacy of nonsteroidal antiinflammatory agents in medical management has not been evaluated, and surgical intervention is not indicated in the acute situation.

Arytenoid dislocation must always be considered, particularly if there is a history of traumatic intubation or multiple intubations after repeated failures of extubation. Laryngeal examination will reveal an immobile vocal cord and the arytenoid displaced in an anteromedial position. This can be confirmed with a CT scan of the larynx and electromyogram (EMG) evidence of innervation of the thyroarytenoid muscle (Miller and Rosenfeld, 1984). Treatment of the acutely dislocated arytenoid is endoscopic reduction. Return to normal function is variable and has been reported to occur with delays in reduction of up to 12 to 16 days after injury (Close et al, 1987).

Posttraumatic stenosis

Acute laryngotracheal injuries caused by blunt or penetrating trauma have been classified according to severity (Olson, 1982), location (Bryce, 1976b), or type of tissue injury (soft tissue, neurogenic, ligamentous, cartilaginous, laryngotracheal, or cricoarytenoid joint rupture) (Richardson, 1981). All three classifications are useful because location, severity, and type of tissue injury are important in determining management. Our approach separates injuries into general categories: soft tissue, ligamentous, and neurogenic and cartilaginous injuries (see the box below). The rationale for this classification are the basic goals of reestablishing skeletal support and mucosal coverage to provide an adequate airway and maintaining a competent airway for phonation and airway protection. Accomplishing these goals requires that each general category of injury be meticulously evaluated and addressed. The initial evaluation, timing of intervention, and indications for open exploration have been discussed.

Acute soft-tissue injuries of the larynx are recognizable as superficial lacerations of the laryngeal mucosa and hematomas on the aryepiglottic folds, false vocal cords, and true vocal cords. If the airway is not compromised, vocal cord mobility is normal, and no exposed cartilage is seen, conservative management with steroids, antibiotics, humidification, and observation is indicated.

Isolated laryngeal soft-tissue injuries severe enough to warrant tracheotomy in situations in which normal laryngeal function cannot be evaluated require direct laryngoscopy. During endoscopy, it is essential to note the level of the true vocal cords and confirm passive mobility of the arytenoid cartilages. These injuries do not usually require correction if passive mobility of the arytenoid cartilages is present and the vocal cords are at the same level. Vocal cord weakness is often due to the mass effect of the hematoma, and motion returns as the hematoma resolves (Cummings et al, 1984a).

Traumatic cartilaginous injuries of the larynx can involve the supraglottis, glottis, or subglottis. In more severe transglottic injuries, any combination of sites may be involved. Acute supraglottic stenosis is most commonly due to traumatic posterior epiglottic displacement posteriorly and superiorly if a horizontal thyroid cartilage fracture is present. An associated hyoid bone fracture may be present. The transhyoid pharyngotomy approach provides the best exposure for isolated supraglottic stenosis (Montgomery, 1989). Entry through the vallecula allows adequate visualization of the supraglottic larynx and hypopharynx without violating the glottic larynx. Mucosal lacerations are closed primarily. Hyoid bone fractures can be reduced and wired, or the body of the hyoid can be excised if marked comminution exists. Thyroid cartilage fractures can be reduced and wired, and the petiole of the epiglottis should be sutured to the hyoid to reposition the petiole anteriorly and prevent a laryngeal inlet stenosis. Internal laryngeal stenting is not required unless large epithelial grafts are used or extensive cartilage comminution is present. Supraglottic resection can be considered for severe supraglottic injuries (Cummings et al, 1984a), but is usually reserved for use after failure of initial open reduction and/or attempts to correct a chronic supraglottic stenosis.

Acute glottic injuries result from vertical fractures of the thyroid cartilage that produice a communication between the larynx and anterior soft-tissue planes of the neck. This may be associated with vocal cord lacerations or arytenoid dislocation. Reestablishment of the anterior commissure and an adequate anterior-posterior dimension of the glottis is an adequate anterior-posterior dimension of the glottis is essential for successful repair. The endolarynx is approached through a midline thyrotomy or by way of the thyroid fracture if it is near the midline. The anterior commissure is divided in the midline under direct vision looking from below. Mucosal lacerations are closed, and the anterior free edges of the false and true vocal cords are sutured through the anterior thyroid perichondrium to prevent fore-shortening. Care must be taken to place the vocal cords at the same level. The petiole of the epiglottis is sutured to the hyiod. A keel is used to reconstruct the anterior commissure as shown (Fig. 108-1) for 3 weeks. A stent is used if more than the anterior commissure is involved (Cummings et al, 1984a).

Acute subglottic injuries involve the anterior cricoid arch and can be caused by laryngotracheal transection. Isolated cricoid fractures are approached via a midline thyrotomy. The previously placed tracheotomy is lowered to below the fifth tracheal ring; the fracture is reduced and wired if possible. Cricoid arch fractures are often severely comminuted, necessitating use of a rigid internal stent. The choice of stent depends on the surgeon's experience and personal preference. The stent is left in place for 6 to 12 weeks (Cummings et al, 1984a).

Acute transglottic injuries can involve the glottis, supraglottis, or subglottis. Again, adequate exposure can be obtained by a midline thyrotomy. Each specific area of the larynx is approached as previously described, and rigid internal stenting for 6 to 12 weeks is required. The principles of primary mucosal repair, anatomic reduction and stabilization of fractures with minimal periosteal elevation, and reconstitution of the anterior commissure and normal dimensions of the larynx should be applied.

Neurogenic injuries usually occur from a penetrating injury to the neck or during complete laryngotracheal transection. Although considerable controversy surrounds the indication for primary neuroraphy, we believe it is indicated to help restore glottic competence and theoretically to prevent denervation atrophy of the intrisic laryngeal muscles.

Cricoarytenoid joint dislocation is considered a ligamentous injury because dislocation or subluxation requires varying degrees of disruption of the posterior cricoarytenoid ligament. The cause, clinical presentation, evaluation, and management are discussed in the discussion of acute post-intubation stenosis. The OHNS should always consider this diagnosis in a patient with external neck trauma or a history of intubation who has odynophagia, throat pain, and hoarseness associated with an immobile vocal cord. The long-term sequela of untreated cricoarytenoid joint injury is fibrous ankylosis of the joint (Close et al, 1987).

Complete laryngotracheal transection is considered a ligamentous injury; it occurs most frequently as a cricotracheal separation. This injury can also occur between tracheal rings and is associated with bilateral recurrent laryngeal nerve (RLN) injury. It can be present without an external neck laceration and is associated with other devastating trauma. Immediate recognition of the injury is vital. A history of blunt injury or a "clothesline" injury to the neck with immediate onset of aphonia, hemoptysis, respiratory distress, and cervical subcutaneous emphysema provides useful clues. When there is an overlying neck wound, the distal stump can be directly intubated to control the airway. Orotracheal intubation is likely to be unsuccessful when no neck wound is present; therefore, urgent tracheotomy must be performed.

Once the airway is established, evaluation must exclude major organ system injury, such as pneumothorax, cervical spine fracture, or intraabdominal, cardiothoracic, or neurologic, or vascular injury. Esophageal injury is very common and must be evaluated with barium swallow (if possible) and careful endoscopy.

Repair of laryngotracheal transection should be carried out as early as possible, preferably within the first 24 hours, to decrease the risk of wound infection. Repair requires end-to-end anastomosis as illustrated in Fig. 108-2. The proximal and distal tracheal stumps are identified and mucosal edges freshened. The distal trachea is gently mobilized with blunt dissection, preserving the blood supply entering laterally. If more than 2 cm of tracheal loss is present, the larynx should be mobilized to reduce tension on the suture line. We prefer a suprahyoid release (see the discussion of chronic cervical tracheal stenosis). Any esophageal lacerations are repaired first in two layers with 3-0 suture (vicryl). The first layer is inverted with a Connell stitch. The tracheal anastomosis is then accomplished by placing 3-0 suture (vicryl) around the tracheal rings (or cricoid) above and below the anastomosis. Sutures are placed submucosally and tied so that the knot is extraluminal. The posterior wall is repaired first. The remaining anastomosis is then completed by first placing all sutures, then tying sutures sequentially from lateral to anterior. The esophageal closure can be optimally reinforced by oversewing with the omohyoid muscle. The sternohyoid muscles can be drawn together in the midline to reinforce the tracheal closure (Cummings et al, 1984a; Montgomery, 1989). If vocal cord paralysis occurs, the recurrent laryngeal nerve on the involved side(s) should be identified in the tracheoesophageal groove and primary neuroraphy accomplished when feasible.

The management of the airway depends on any associated laryngeal injury that would require stenting. If a stent is needed, a low tracheotomy is performed befotre cricotracheal anastomosis. If a stent is not needed, or a low cervical tracheal anastomosis has been accomplished, the patient should be intubated for 4 to 5 days then extubated in the operating room so the airway can be directly visualized to ensure satisfactory healing and lumen caliber.

Surgical Management of Chronic Stenosis

Supraglottic stenosis

Chronic hypopharyngeal stenosis usually results from unrecognized acute blunt injury to the hyoid and thyrohyoid membrane. The direction of force is posterosuperior and results in several discrete injuries: (1) the epiglottis can be adherent to the posterior or lateral hypopharyngeal walls; (2) the hyoid bone can be fractured and displaced posteriorly with the epiglottis, producing laryngeal inlet stenosis; (3) a horizontal web of the posterior hypopharyngeal wall may form at the level of the superior aspect of the epiglottis; or (4) postcricoid stenosis may result in stenosis of the esophageal introitus (Montgomery, 1989). The type and extent of the stenosis can be evaluated by indirect laryngoscopy, direct laryngoscopy, and barium swallow if the inferior extent is difficult to evaluate.

The surgical approach is through a transhyoid pharyngotomy. Tracheotomy is essential if it has not been previously performed. A horizontal skin incision is made over the hyoid bone, which is then identified. If the hyoid is fractured, attempts are made to reduce and wire it into its normal anatomic position; otherwise the body of the hyoid can be excised. The vallecula is entered and opened to provide satisfactory exposure. This mucosal incision can be extended to a lateral pharyngotomy if needed, taking care to preserve the superior laryngeal neurovascular pedicle.

Adhesions of the epiglottis to the hypopharyngeal walls can be managed by division of the adhesion along its long axis, submucosal excision of scar, and primary mucosal closure. When a horizontal web or shelf is present, a vertical incision(s) is made through the web, and scar is excised. Mucosal flaps are undermined to allow closure of the incision in a horizontal line. If necessary, superiorly based mucosal advancement flaps can be employed. If the hypopharyngeal stenosis is so extensive that division of bands and excision of scar result in extensive denuded area, consideration should be given to skin grafting these areas. Hollow silicone esophageal stents have also been used to assist healing of a skin graft (Montgomery, 1989).

Laryngeal inlet stenosis, as previously mentioned, results from posterior displacement of the hyoid and epiglottic cartilage and can be accompanied by a fracture through the thyroid notch. This injury is approached through a laryngofissure; the thyrohyoid membrane is divided in the midline to excise the base of the epiglottis, which protrudes over the glottis. After identification of the base of the epiglottis, the anterior fascia and perichondrium are incised in an inverted V fashion to the cartilage. Mucoperichondrium is elevated off the laryngeal surface of the epiglottis, allowing excision of this inverted V-shaped wedge of the base of the epiglottic cartilage, perichondrium, and fascia. The previously elevated mucoperichondrium on the laryngeal surface of the epiglottis is incised in the midline, and the resultant flaps are turned outward and sewn to the free edge of the anterior epiglottic perichondrium (Fig. 108-3). The thyrotomy is closed, and stenting is not required (Montgomery, 1989).

Glottic stenosis

Anterior glottic stenosis

Anterior glottic stenosis in adults can be caused by external trauma resulting in a thyroid cartilage fracture and mucosal disruption. Internal laryngeal trauma, from either endotracheal intubation or surgical removal of mucosa from the anterior edges of both vocal cords, can cause the two opposing raw mucosal edges to heal together. A thin web that extends more than 3 to 4 mm posteriorly along the vocal fold can produce hoarseness. A thicker web, or one that extends farther posteriorly, can cause significant airway obstruction (Dedo, 1979). The presence of hoarseness or airway compromise indicates a need for surgical intervention. The OHNS must consider that excision of the anterior glottic scar will re-create the conditions that caused the original stenosis. Therefore, successful repair requires physical separation of the opposing edges until remucosalization is complete.

Endoscopic management of anterior glottic stenosis can be considered when the web does not extend below the inferior edge of the true vocal cord and when the posterior commissure is normal (Dedo, 1979; Parker and Das Gupta, 1987). Division of the anterior webs can be performed by suspension microlaryngoscopy and either microlaryngeal instruments or the CO_2 laser. Excess scar is removed, and a keel is placed endoscopically and secured externally via wires or heavy suture placed through the thyrohyoid membrane (Fig. 108-4). Different keel designs and compositions have been described. The principles in designing keels are the following: (1) the material used should be inert; (2) the length should be sufficient to extend from the cricothyroid membrane to at least 2 to 3 mm above the anterior commissure; (3) if the keel extends superiorly over the petiole of the epiglottis, the anterior edge of the keel should make an angle of 120 degrees because this is the angle of the epiglottis and the anterior tracheal wall; this will minimize granulation tissue formation at the petiole of the epiglottis; and (4) the posterior wing of the keel should lie at the vocal processes and should not touch the posterior commissure (Dedo, 1979; Parker and Das Gupta, 1987). The keel is removed after 2 to 4 weeks and granulation tissue is removed concurrently.

An external laryngofissure approach should be considered when the anterior glottic stenosis extends more than 5 mm subglotically, when it accompanies a laryngeal inlet stenosis, or when it is associated with a shortened anterior-posterior glottic apperture produced by a thyroid cartilage fracture or endoscopic approaches have failed. Resection of scar should not be overzealous, and mucosa should be preserved whenever possible. Successful results have been achieved with the Montgomery umbrella silicone keel used for 2 to 3 weeks (Fig. 108-4) or with the McNaught tantalum keel (Dedo, 1979; Montgomery, 1989).

Posterior glottic stenosis

Posterior glottic stenosis is most commonly caused by endotracheal intubation. The degree of injury is variable and has been classified as follows: (1) interarytenoid adhesion with a posterior sinus tract, (2) posterior commissure stenosis, (3) posterior commissure stenosis with unilateral cricoarytenoid ankylosis, or (4) posterior commissure stenosis with bilateral cricoarytenoid ankylosis (Bogdasarian and Olsen, 1980). The posterior scarring can frequently extend to the subglottis. The major therapeutic challenge is to reestablish a satisfactory airway and preserve the voice, which is often normal.

Endoscopic repair of posterior glottic stenosis is successful in carefully selected patients. Those with an interarytenoid web and posterior sinus tract have been treated with simple division of the web. A significant number of these patients restenose, particularly those who have had a tracheotomy (Dedo and Sooy, 1984). A soft, sponge-filled finger cot stent has been advocated in this situation to separate the raw opposing surfaces. It can be placed endoscopically and remain for 2 weeks (Bogdasarian and Olsen, 1980).

Posterior commissure stenosis can be managed endoscopically with a CO_2 laser or via a laryngofissure. Creation of a posterior microtrapdoor flap is successful when a posterior sinus or a 3- to 4-mm posterior interarytenoid scar is present (Dedo and Sooy, 1984). Failure of this technique occurred when there was arytenoid fixation or a scar greater than 1 cm in vertical height (Duncavage et al, 1987). When posterior interarytenoid mucosa was insufficient to create a trapdoor flap (< 3 to 4 mm), interarytenoid scar was resected with preservation of mucosa through a hockey stick incision. A 0.025-inch-thick synthetic implantation fabric (Teflon) keel was placed endoscopically and left for 4 to 6 weeks. This was considered to widen the interarytenoid mucosa sufficiently to allow a microtrapdoor flap. However, failures occurred in all patients who had arytenoid fixation (Langman et al, 1989). Several authors (Bogdasarian and Olsen, 1980; Cummings et al, 1984b; Montgomery, 1973; Simpson, 1982) recommend open repair via a laryngofissure approach. Repair is effected by developing a superiorly based mucosal flap, excising scar and fibrosed interarytenoid muscle, and repositioning the mucosal flap to provide immediate epithelial coverage. Internal stenting is not required when both arytenoids are mobile. Care is taken not to enter the cricoarytenoid joints if both arytenoids are mobile. It should be noted that successful surgical repair is an elusive goal with this entity.

Posterior glottic stenosis with arytenoid fixation has been traditionally managed through an external approach. If, after development of a mucosal flap and resection of scar, one arytenoid is freely mobile, resection of the fixed arytenoid is unnecessary. When bilateral arytenoid fixation exists, removal of the least mobile arytenoid is necessary to achieve a satisfactory airway. Denuded mucosal surfaces are covered with mucosal flaps, skin, or mucosal grafts. Stenting for 2 to 3 weeks is necessary, either with a conforming silicone laryngeal stent (Montgomery, 1973) or with a soft finger cot stent (Bogdasarian and Olsen, 1980). Exploration of the fixed cricoarytenoid joints with lysis of adhesions without arytenoidectomy has recently been advocated. Fibrous bands on the medial aspect of the cricoarytenoid joints are divided and the arytenoids stented in full abduction for 2 to 3 weeks; stent removal and aggressive speech therapy follow. Return of vocal cord mobility has been described in 9 of 10 patients treated in this manner (Goodwin et al, 1988; Schaefer et al, 1986).

Complete glottic stenosis

Complete glottic stenosis usually results from unrecognized severe extralaryngeal trauma. Injury limited to the glottis is unusual; there is often associated subglottic injury, which must be addressed concurrently. Endoscopic treatment is rarely indicated because of the severity and nature of the injury. However, isolated complete glottic stenosis has been successfully managed by endoscopic incision and placement of a synthetic fabric (Teflon) keel (Langman et al, 1989). The reported experience is limited to two patients, both of whom required a second procedure for correction of a residual posterior glottic stenosis. Further follow-up observation is required to evaluate the efficacy of this procedure.

The mainstay of treatment involves an open laryngofissure apprach. The stenosis must be divided in the midline and excessive scar resected while preserving mucosa and developing mucosal flaps from the aryepiglottic folds for coverage. If extensive areas are devoid of mucosa, epithelial grafts of buccal mucosa, grafts of nasal septal mucosa, or split thickness skin grafts (STSGs) may be used. Large STSGs may cause excessive crusting. The grafts are sutured in place and stented with a form-fitting laryngeal stent for 4 to 8 weeks (Montgomery, 1973). When this is removed, an umbrella keel is placed in the anterior commissure for 2 weeks.

An alternative approach is reconstruction with an epiglottic flap. This is indicated in severe glottic stenosis with a >50% reduction in the anterior-posterior dimension of the glottis, glottic-subglottic stenosis, or glottic-supraglottic stenosis with an intact epiglottis (Kennedy, 1980). The repair is approached through a midline thyrotomy, and the thick scar is transected in the midline. Submucosal excision of scar can be attempted and the mucosa repositioned and secured with 4-0 chromic suture. The base of the epiglottis is identified, and the medial thyroepiglottic ligament is transected. The epiglottis is pulled inferiorly to reach the anterior cricoid arch. The epiglottic flap is sutured with 3-0 Vicryl to the outer anterior edges of the thyroid cartilage laterally and cricoid cartilage inferiorly. This results in an epithelialized, widened anterior commissure. Several cartilage-splitting incisions may be used to allow the petiole to be folded upon itself to make a sharper anterior commissure (Cummings et al, 1984b).

Glottic stenosis secondary to vocal cord immobility

Glottic stenosis caused by a bilateral vocal cord immobility may be neurogenic or mechanical in origin. Bilateral vocal cord paralysis in the past was most commonly caused by thyroid surgery; today, blunt or penetrating trauma is the primary cause. Mechanical fixation can result from cricoarytenoid joint arthritis or from scarring of the joint secondary to orotracheal intubation. The management of the latter in conjunction with posterior glottic stenosis has been discussed. Differentiation between mechanical fixation and neurogenic paralysis is established by direct laryngoscope. Palpation of the arytenoid to assess mobility is vital. Joint excursion should be uninhibited. Passive medial movement of the contralateral arytenoid when the ipsilateral arytenoid is displaced laterally suggests interarytenoid scar. EMG findings of denervation or action potentials of the vocalis muscle is very useful to document neurologic integrity, particularly when direct observation of vocal cord moevement with the patient lightly sedated yields equivocal data. These patients usually have a preexisting tracheotomy, which reduces posterior cricoarytenoid (PCA) muscle activity, making active lateral vocal cord excursions difficult to visualize unless the tracheotomy tube is plugged temporarily.

Patients with bilateral abductor paralysis secondary to neurogenic injury and without cricoarytenoid fibrosis may be initially treated in one of two ways: Vocal cord lateralization can be performed endoscopically with laser excision of a wedge of thyroarytenoid muscle. The vocal cord is lateralized by introducing two 18-gauge needles through the thyroid lamina, obe above and one below the midportion of the vocal cord. Sutures are passed through the needles, drawn out through the mouth, tied together, then drawn sufficiently taught to lateralize the vocal cord 3 to 4 mm. Sutures are secured externally and removed in 1 to 2 weeks (Montgomery, 1989). This procedure is reported to have a 70% initial success rate, and all initial failures had cricoarytenoid joint fixation (Remsen et al, 1985).

The technique of nerve muscle transposition was introduced by Tucker (1976), and good results have been reported by others (Applebaum et al, 1979; May et al, 1980). The posterior cricoarytenoid muscle is reinnervated with a transposed nerve muscle pedicle consisting of the anterior belly of the omohyoid muscle and its nerve from the ansa cervicalis. Uniform success with this procedure has not been experienced by all investigators, and lateralization may be achieved by fibrotic tethering of the extralaryngeal muscles, instead of true reinnervation (Cummings et al, 1984b). Alternatively, selective reinnervation of the abductor branch of the recurrent laryngeal nerve with a split phrenic nerve graft has been proposed (Crumley et al, 1980). In a series of 4 patients followed for longer than 15 months, no return of visible vocal cord abduction was seen (Crumley, 1983). One patient had a subjective improvement in the airway, which was documented by pulmonary function tests. All patients were considered failures, but selective laryngeal reinnervation remains an area of active investigation (Crumley, 1990).

Bilateral abductor paralysis can be successfully managed with arytenoidectomy with or without vocal cord lateralization. Arytenoidectomy can be approached endoscopically or externally, depending on the surgeon's personal experience and preference.

Endoscopic arytenoidectomy was first introduced by Thornell in 1948 but was technically difficult. Use of the CO_2 laser has become increasingly popular because it avoids complications of an external approach and allows immediate assessment of airway size. An excellent technical description of endoscopic laser arytenoidectomy is described (Ossoff et al, 1983) and requires removal of the entire arytenoid except the muscular process. Care must be taken to prevent injury to the mucosa of the interarytenoid cleft in order to prevent development of a posterior glottic web, which can further compromise the airway. Arytenoid perichondritis is a potential complication, and administration of perioperative antibiotics is recommended. The disadvantage of this procedure is that healing causes additional lateralization through scar contracture. The degree to which this occurs varies and it may produce an excessively breathy voice or an inadequate airway. Use of a lateralization suture or a finger cot stent may improve the final result by controlling the degree of lateralization.

The most popular external approaches for arytenoidectomy are the Woodman procedures, the most popular being via a midline thyrotomy. The Woodman arytenoidectomy involves exposure of the arytenoid cartilage via a posterolateral extralaryngeal dissection through the inferior constrictor muscle and remaining deep to the mucosa of the piriform sinus. The entire arytenoid cartilage is resected except the vocal process. A submucosal suture is placed through the vocal process and anchored around the vocal process to lateralize the vocal cord, 6 mm in males and 5 mm in females (Sessions et al, 1976; Woodman, 1946). Other authors believe that tethering the vocal process around the inferior cornu of the thyroid cartilage may reposition the cord inferior to the opposite true vocal cord and recommend suturing to the thyroid lamina at the vocal cord level (Cummings et al, 1984b) or around the superior corny (Montgomery, 1989). A 60% to 80% success rate can be anticipated. If the procedure is unsuccessful, the contralateral side can be resected or a completion arytenoidectomy via a laryngofissure with suture lateralization of the vocal cord can be performed.

Subglottic stenosis

Endoscopic treatment of subglottic stenosis with the CO_2 laser requires careful patient selection. The predictive factors for failure have been described earlier and have been confirmed by others (Dedo and Sooy, 1984; Duncavage et al, 1987; Simpson et al, 1982).

A moderately reliable method of treating circumferential subglottic stenosis is CO_2 laser excision and repair with a microtrapdoor flap (Dedo and Sooy, 1984). The technique requires laser incision in the superior surface of the scar and submucosal excision of scar. An inferiorly based, rectangular mucosal flap is created by two lateral knife incisions. The preserved flap does not completely cover the lasered area, but it does divide the raw concave area into two flat lateral raw areas (Fig. 108-5), which heal rapidly. A 90% success rate was reported in 10 patients, all of whom had scars less than 10 mm in vertical height. A large flap that can potentially obstruct the airway through a ball-valve effect should not be created. Failure occurred if associated posterior glottic stenosis or arytenoid fixation was present (Duncavage et al, 1987). An alternative method of radial incision of the stenosis at 2:00, 3:00, 6:00, and 9:00 followed by bronchoscopic dilation has been proposed (Shapshay et al, 1987). This series of patients was small, follow-up observation involved 1 year, and thus success was not assumed.

External repair is indicated after failure of endoscopic techniques or when the extent of the stenosis is severe and factors are unfavorable for an endoscopic approach. A variety of techniques are available, and in selecting the appropriate repair, the OHNS must anticipate the amount of cartilage needed for luminal augmentation and the possibility that the scar resection requires epithelial grafting.

Subglottic stenosis secondary to extensive mature scar but with adequate cartilaginous support can be approached by laryngofissure. Subglottic scar is resected to cricoid perichondrium and is relined with buccal mucosa or split thickness skin. The graft is preferably sewn directly to the defect or can be reversed and sewn around a stent that is fixed in place (Montgomery, 1989). When cartilaginous support or luminal augmentation is also required, a variety of autogenous cartilage grafts are available.

The hyoid-sternohyoid muscle interposition graft has been extensively used with approximately 70% success rate in adults (Burstein et al, 1986; Wong et al, 1978). This technique can be applied to isolated subglottic stenosis or subglottic stenosis in combination with anterior glottic or tracheal stenosis. The procedure employs a vascularized segment of the body of the hyoid pedicled on the sternohyoid muscle and its adjacent periosteum. The length of bone can be tailored to the length of the stenosis; it is interposed vertically into the stenosis and secured with four-point fixation. A stent is not used unless an epidermal graft is required after scar excision to minimize possible graft resorption by pressure necrosis.

The advantages of this technique include immediate reconstruction with a single operative field, theoretically improved tissue survival with minimal graft remodeling, and versatility in augmenting glottic, subglottic, and upper tracheal stenoses. The long-term survival of the bone graft has not been conclusively demonstrated. The disadvantages of this graft are its narrow width and concave shape, which limit its use in more extensive subglottic and tracheal defects. Also, additional procedures are required to remove granulation tissue, which frequently develops.

The thyroid cartilage-sternothyroid pedicled composite graft was developed to overcome the limitations of the hyoid-sternohyoid graft (Fry et al, 1985). A large central piece of thyroid ala attached to the sternothyroid muscle through its perichondrium is harvested. A flap of contralateral thyroid alar perichondrium is harvested in continuity with the ipsilateral perichondrium (Fig. 108-6) and serves as internal lining when the composite graft is transposed. Stenting for 1 to 6 weeks is required.

This technique offers the advantages of the hyoid-sternohyoid graft, except that it cannot be used for glottic stenosis. A larger piece of cartilage is available to reconstruct more extensive devfects. The internal perichondrial transposition allows for remucosalization with minimal granulation tissue formation.

A variety of free autogenous cartilage grafts have been used for luminal augmentation. These grafts all have a variable amount of resorption and require prolonged stenting to allow resorbed cartilage to be replaced by firm, mature scar. Costal cartilage grafts have the advantage of providing large grafts that are easily sculpted. Specific details of graft tailoring have been well described (Zalzal and Cotton, 1986). Composite nasal septal cartilage grafts have been used successfully in 11 of 16 patients with stenosis of the larynx and upper trachea (Duncavage et al, 1989). Stenosis of up to 3 cm in vertical height can be repaired, and the respiratory epithelium is a theoretic advantage because it provides immediate resurfacing with a match of epithelium from the stenotic area. A stent was not used, and the graft was not used in children to prevent injury to nasal growth centers. A variety of other autogenous grafts, including auricular cartilage (Morgenstein, 1972), clavicular bone, and free hyoid bone, have been used but have not received uniform acceptance.

Division of the posterior cricoid lamina should be considered when severe subglottic stenosis is present with posterior glottic stenosis or for complete glottic and subglottic stenosis. This is approached through a laryngotracheal fissure, and the entire posterior cricoid lamina is divided vertically in the midline to the level of the postcricoid submucosa (Rethi, 1956). Scar excision is not necessary, and the interarytenoid muscle is divided if it is fibrosed. Prolonged rigid stenting is required for at least 3 months. Interposition cartilage grafts with perichondrium can be harvested from the thyroid lamina for posterior support (Montgomery, 1989). Anterior luminal augmentation can be performed as described later.

Partial cricoid resection with thyrotracheal anastomosis is considered when other methods have failed. Several authors have reported good results and specific technical details (Bryce, 1979a; Conley, 1953; Ogura and Biller, 1971). This procedure should only be performed in adults and is limited to stenosis involving the cricoid and upper trachea. There should be approximately 1 cm of normal lumen below the glottis. The main risks of this procedure are injury to the recurrent laryngeal nerves and anastomotic dehiscence with restenosis.

The procedure involves exposure of the involved laryngotrachea and attempted indentation of the recurrent laryngeal nerves in the tracheoesophageal groove. This often is impossible because of extensive scarring; therefore, dissection of the trachea is performed in the subperichondrial plane. The inferior resection line is made immediately below the stenosis, beveling the anterior tracheal wall. The superior limit can include all of the cricoid up to the posterior lamina just below the cricothyroid joint. Care is taken not to injure the recurrent laryngeal nerves, which pass immediately posterior to the cricothyroid joints. The tracheotomy is lowered and the anastomosis is accomplished with 3-0 interrupted suture (Vicryl) placed submucosally and tied extraluminally. Stenting is not required. Laryngeal release procedures are usually necessary (see the next section), and the neck is kept in flexion for 7 to 10 days postoperatively to minimize tension on the anastomosis.

A sliding flap tracheoplasty, which is a variation of the cricoid resection and thyrotracheal anastomosis, was recently described (Gates and Tucker, 1989). The procedure involves resection of the anterior cricoid arch and first two tracheal rings and development of an inferiorly based anterior tracheal wall flap from the third through the sixth rings, which is advanced and anastomosed to the thyroid cartilage superiorly. Patients selected for this procedure must have a subglottic stenosis involving only the anterior cricoid arch and first ring, intact posterior wall, mobile vocal cords, and uninvolved segment of mucosa below the glottis.

Cervical tracheal stenosis

Cervical tracheal stenosis in adults most commonly results from trauma produced by intubation, tracheotomy, or blunt external trauma to the neck. Other causes include benign and malignant neoplasms, inflammatory diseases, and systemic autoimmune disease. An excellent discussion of the anatomy, pathophysiology, and differential diagnosis of tracheal stenosis has been presented (Spector and Anderson, 1986).

When surgical repair of tracheal stenosis is considered, regardless of the cause, it is essential to determine location, length, composition, extent of airway stenosis, and neurologic integrity of the larynx through indirect laryngeal examination, bronchoscopy, and radiographic studies. In most instances, cervical tracheal stenosis, anterior wall collapse, or complete stenosis.

Airway management should also be considered preoperatively and discussed with the anesthesiologist. If a tracheotomy is not present or is not planned, Grillo states that patients should be maintained on spontaneous respiration and that the anesthesia should be conducted so that the patient will breathe spontaneously after completion of the procedure. This is particularly important if a Montgomery T-tube is used as part of the reconstruction. At the time of reconstruction, if the airway is 5 mm or less, dilation is performed initially under general anesthesia with pediatric bronchoscopes serially to prevent hypercapnia. If the lumen is larger than 6 mm in diameter, intubation is carried out above the lesion and dissection performed carefully to prevent airway obstruction (Grillo, 1979). If a tracheotomy is planned postoperatively, it should be performed under local anesthesia at the onset of reconstruction.

Cicatricial membranous stenosis

Granular or fibrous stenosis of the cervical trachea with intact cartilage can initially be treated endoscopically. CO_2 laser excision of granular stenosis is useful because tracheotomy can be avoided and the granular stenosis can be resected accurately with minimal bleeding. If the stenosis is circumferential, partial resections should be staged 2 to 4 weeks apart to prevent formation of a circumferential denuded area of trachea that can restenose. Fibrous stenosis can be excised by a microtrapdoor technique as previously discussed for subglottic stenosis (Dedo and Sooy, 1984).

Open repair of a cicatricial membranous stenosis requires approaching the stenosis through a vertical midline incision through the anterior tracheal wall to expose the entire length of the stenosis. Care is taken to prevent lateral dissection because the vascular supply to the cervical trachea from the inferior thyroid artery enters the tracheal laterally. The scar is resected under direct visualization, and the tracheotomy is lowered below the stenosis. A buccal mucosal, dermal, or split thickness skin graft can be sewn directly to the mucosal defect or around a stent. The surgeon may elect to use a variety of stents, including a Montgomery T-tube. If luminal augmentation is required, a hyoid-sternohyoid or cartilage graft can be used.

Anterior wall collapse

Anterior wall collapse can result from anterior blunt neck trauma but more commonly results from tracheotomy. Montgomery categorizes these injuries as suprastomal, stomal, or infrastomal (1989). In this type of stenosis, a well-mucosalized posterolateral tracheal wall and residual cartilage in the area of the stenosis must be present (Cummings et al, 1984b).

A suprastomal and stomal stenosis can be approached and managed as described for cicatricial membranous stenosis. However, restoration of the anterior wall is essential. This can be accomplished by stenting the lumen open with a T-tube or a firm stent over a tracheostomy tube (Aboulker stent) and repairing the anterior wall with a cartilage graft or mobilizing the sternohyoid muscles and securing them together over the defect (Fig. 108-7). In either instance, prolonged stenting is required (Cummings et al, 1984b; Montgomery, 1989).

Wedge resection of an anterior tracheal wall stenosis can be considered if (1) the stenosis is limited to two or three rings with significant loss of cartilage that would preclude stenting; (2) posterior wall mucosa is intact; or (3) stenosis is stomal or suprastomal. The procedure requires adequate exposure of the involved trachea, including at least one ring above and below the stenosis. Subperichondrial dissection is carried out carefully around the involved trachea to prevent injury to the recurrent laryngeal nerves. The stenosis is resected, preserving posterior tracheal wall mucosa. An oroendotracheal tube is passed through the anastomosis, and the cartilaginous trachea is reanastomosed with submucosal 3-0 sutures (Vicryl) tied extraluminally. The patient is extubated when awake and alert, and granulation tissue is endoscopically excised as early as possible (Cummings et al, 1984b).

Complete tracheal stenosis

Segmental resection and primary anastomosis provide optimal results for complete tracheal stenosis (Grillo, 1972, 1979). The average length of the adult trachea is 11 cm (range 10 to 13 cm), and there are 14 to 20 tracheal rings. With hyperextension of the neck, 50% of the trachea is cervical (Spector and Anderson, 1984). Approximately 50% of the trachea (5 to 7 cm) can be safely resected and anastomosed primarily (Grillo, 1979) with appropriate mobilization techniques. This procedure avoids implant material and is performed in one stage, but places the esophagus, innominate artery, and recurrent nerves at risk of injury.

The procedure is essentially the same as a wedge resection, except that dissection requires excision of the posterior membranous wall. The anterior cricoid arch may also be included in the resection. An oroendotracheal tube is passed distal to the anastomotic site, and the anastomosis is performed with 3-0 submucosal sutures (Vicryl) placed around a tracheal ring and tied extraluminally.

Adequate laryngeal and tracheal mobilization is required (see laryngeal release procedures) to relieve tension from the anastomosis. The neck is placed in extreme flexion, and a stay stitch is placed from chin to sternum (Cummings et al, 1984b).

Extensive cervical tracheal and laryngotracheal stenosis not amenable to segmental resection and anastomosis can be treated with a staged through reconstructive technique. This multistage technique is outlined in Fig. 108-8. The essential steps require creation of a large tracheostoma by sewing cervical neck skin to residual tracheal mucosa. The second stage requires formation of a rigid anterior wall by insertion of marlex mesh under adjacent cervical skin. Finally, the closure is obtained by tubing skin and marlex mesh anteriorly to close the stoma and then advancing cervical skin as a second layer. A 76% success rate has been reported (Biller et al, 1986). A variation of this technique, using a "rotary door" flap of sternohyoid muscle and overlying skin, has been described (Eliachar et al, 1989). Extensive crusting can result with either of these repairs, since extensive use is made of neck skin to resurface the anterior tracheal wall.

Laryngeal release procedures

Tracheal mobilization and laryngeal release techniques are required when a gap greater than 3 cm in tracheal continuity occurs in young patients. Older patients lose elasticity of the annular ligaments of the trachea and therefore require release techniques when more than 1 to 2 cm is resected.

There are three techniques for gaining extra length for end-to-end anastomosis. The first is incision of the annular ligaments. This can add up to 2.5 cm but is most useful in younger patients. Incision must be placed on one side of the lateral trachea above the anastomosis and on the opposite side below the anastomosis to preserve the blood supply to both tracheal segments (Montgomery, 1989).

The second technique involves superior mobilization of the distal trachea from the thorax (Grillo, 1979), which can achieve 6 cm of mobilization. This technique requires transection of the left mainstem bronchus and end-to-side anastomosis with the right mainstem bronchus and carries with it the risks of mediastinal dissection.

The third method involves laryngeal release procedures, which can gain 5 cm of tracheal mobilization. The infrahyoid release involves transecting the sternohyoid, omohyoid, and thyrohyoid muscles at the level of the superior border of the thyroid cartilage. The greater cornua of the thyroid cartilage are divided bilaterally, and the thyrohyoid membrane is sectioned. This procedure carries risk of injury to the superior laryngeal nerve and is associated with prolonged dysphagia.

Our preferred technique is a suprahyoid laryngeal release (Fig. 108-9). This technique requires transecting the insertion of the mylohyoid, geniohyoid, and genioglossus muscles to expose the preepiglottic space. The stylohyoid insertions are transected and the body of the hyoid is transected just medial to the insertion of the digastric tendon. This allows the body of the hyoid, thyroid cartilage, cricoid cartilage, and proximal trachea to drop inferiorly. Flexion of the neck allows an additional 1 to 2 cm of length (Montgomery, 1989).